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Effect of Soil Structure Interaction on RC Building with TMD as Energy Absorbing Storey

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Abstract: This paper presents however soil–structure interaction affects the seismal performance of Tuned Mass Dampers (TMD) once put in on flexibly primarily based structures. The tuned mass damper (TMD) as a new endoergic system is one in every of the accessible systems of structural management. Tuned Mass Damper (TMD) could be a passive system that absorbs energy and reduces response of vibration. TMD is found to be a straightforward effective cheap and reliable means that for decreasing undesirable vibration of structure caused by seismal or wind excitation. This analysis explores further high structure as tuned mass damper in building system for reducing the seismal response of tall structure and mitigating harm. The projected structural configuration separates the higher structure of structure to act as the 'tuned' mass. This extra structure is additionally of RCC buildings and its beam and column sizes are smaller than that of building. The effects of SSI on the functioning of tuned mass dampers (TMD) for seismal vibration management are investigated. The behavior of flexible-base structures with connected TMD, subjected to earthquake excitations has been investigated. The impact of TMD on the seismal response of structure is studied. The non-linear time history analysis is carried out to access the parameters such as storey displacement, storey shear, storey drift by considering effect of soil structure interaction. It's seen that TMD within the style of weak structure at the highest of building reduces the displacement, structure shear, structure drift.

Keywords: Seismal response, Optimum parameters, tuned mass damper (TMD), mass ratio, Storey displacement, Shear force, Storey shear.

1. INTRODUCTION

In structural engineering the major goal has been the, maintaining the structural stability against effect of various forces acting on the structure. Earthquake and wind are the two important external forces that need to be taken in account while designing a structure, as they can greatly affect stability of structure. In last years the importance of Soil Structure Interaction (SSI) on earthquake response of structure has a lot of appealing and intensive. The soil flexibility is that the main problem for top rise structure once they made over soft or medium soil strata. The dynamic parameters (fundamental natural period, floor shear, floor drift etc.) of the structure considerably altered because of soil flexibility. During associate earthquake, unstable force demand and deformation characteristics of structure and soil elements of the footing of building will alter or amendment a lot of considerably. Efforts have led to incorporation of techniques like base isolation, active control and passive control devices.

[Fahim Sadek et al][1] The optimum parameters of tuned mass dampers (TMD) that result in considerable reduction in the response of structures to seismic loading are presented. The parameters are used to compute the response of several single and multi-degree-of-freedom structures with TMDs to different earthquake excitations. The results indicate that the use of the proposed parameters reduces the displacement and acceleration responses significantly. [Rahul Rana et al][2] This paper summarizes the results of a parametric study performed to enhance the understanding of some important characteristics of tuned mass dampers (TMD). The El Centro and Mexico excitations are used for time-history analysis. From the time-history analyses on SDOF structure-TMD system, it was seen that for large damping of structure, TMD was not found to give much response reduction. [O. R. Jaiswal et al][3] A simplest form of TMD is introduced in the form of a weak story at the top of the structure. The mass of the top story is kept around 3 to 5 % of the total weight of the structure. To satisfy this condition the sizes of column, beam and slab are reduced. Also walls are not provided to this story. Time history analysis of structure is carried out. The result obtained by response spectrum analysis of structure with TMD showed that the forces in column reduce by 20% to 40%. [Thakur V.M. et al][4] In this paper TMD is used as soft story which is considered to be made up of RCC, constructed at the top of the building. A six storied building with rectangular shape is considered for analysis. Analysis is done by FE software SAP 2000 by using direct integration approach. TMDs with percentage masses 2% & 3% are considered. Their result show that a soft storey at the top of building reduces top building deflection by about 10 to 50%. In these study a straightforward style of Tuned Mass Damper (TMD) has been projected. [G.S. Balakrishna et al][5] here a 6 storeyed regular building is proposed to be analyzed using SAP2000 v14 with viscous damper (VFD), with Tuned Mass Dampers (TMD) and without any damping device. Tuned Mass Dampers with varying mass ratios of 2%, 3% and 5% was applied. Time History Analysis was carried out by applying the Bhuj (2001) intensity of earthquake. A comparative study was done after the analysis of regular building with Tuned Mass Dampers, with Viscous Fluid Dampers and without any damping device. For the regular building frame, 3% TMD is found to effectively reduce base shear by about 10-35% and top storey displacement by upto 10-30% (amongst 2%, 3% and 5% TMD's). TMDs are easy to construct and implement on top of buildings compared to implementation.

2. THEROTICAL BACKGROUND

A. Tune Mass Damper

It consists of a secondary mass with properly tuned spring and damping components, providing a frequency-dependent physical phenomenon that will increase damping within the primary structure. The frequency of the damper is tuned to a specific structural frequency so once that frequency is worked up, the damper can resonate out of part with the structural motion. Then the surplus energy that's designed up within the structure are often transferred to a secondary mass and is dissipated by the dashpot thanks to relative motion between them at a later time. Mass of the secondary system varies from 1-5% of the structural mass.

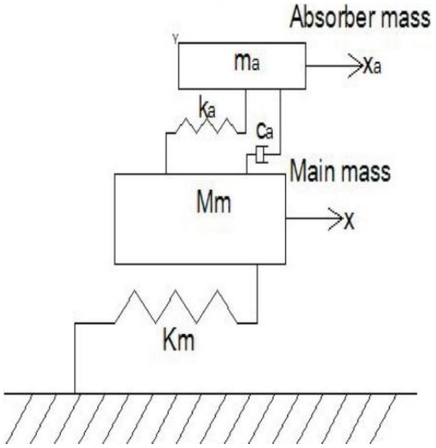


Figure 1: A schematic representation of damped vibration absorber suggested by Den Hartog [3]

B. TMD as A Soft Storey

The soft structure are going to be created from concrete and its columns, beams, and block sizes are going to be smaller than columns, beams, and block sizes alternative stories of the building. The height, member sizes of sentimental structure are going to be devised supported the principle of TMD i.e. the natural frequency of TMD (soft storey) ought to have same natural frequency as that of main building.

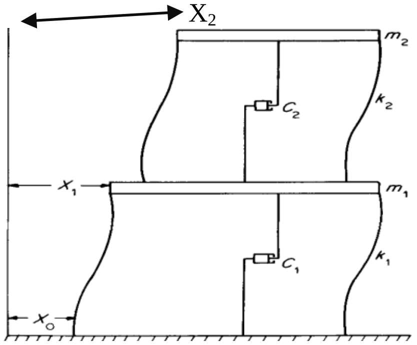


Figure 2: SDOF Structure with Soft-Storey at top

C. Optimum parameter of TMD

[Fahim Sadek et al] formulated optimum parameters of TMD for SDOF and MDOF system, which are given below. For undamped structure the tuning ratio 'f' is found to be equal to 1/ (1+μ) and the damping ratio 'ξ' is equal to $\sqrt{\mu / (1+\mu)}$. Also for damped structure the following equations were obtained,

$$f = \frac{1}{1+\mu}\left[1-\beta\sqrt{\frac{\mu}{1+\mu}}\right] \qquad \xi = \frac{\beta}{1+\mu}+\sqrt{\frac{\mu}{1+\mu}}$$

Where, f = Tuning ratio   ξ = Damping ratio   K = Stiffness of structure
k = Stiffness of TMD   C = damping of building   C = damping of damper
M = mass of structure   m = mass of TMD   μ = mass ratio
$\square_0$ = Natural frequency

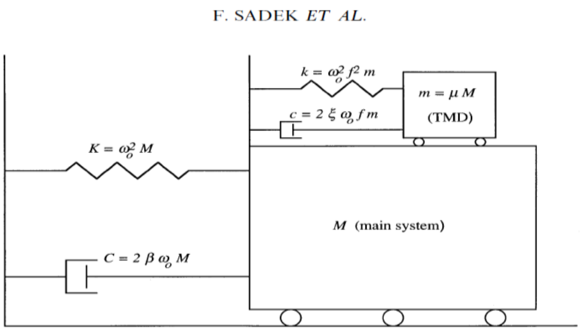
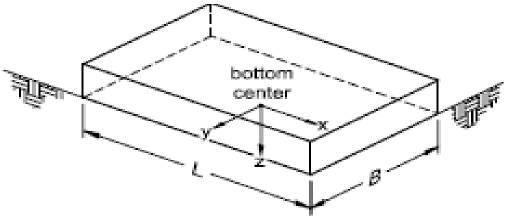


Figure 3: Tuned Mass Damper mounted on a main Structure [1]

D. Soil-Structure Interaction and Structural Response

In this present paper, substructure methodology is employed for the implementation of SSI into analysis. The movement regarding 3 axes has been thought-about. Shallow isolated footing resting on varied soil varieties, 3 translational stiffness springs has been applied in 2 horizontal directions and one vertical direction i.e. X-Y-Z direction severally and equally 3 rotational stiffness springs has been applied in X-Y-Z direction to feature SSI into the analysis, soil spring stiffness equations are taken from FEMA356 (George Gazetas 1991).



Orient axes such that $L \geq B$

Figure 4: Orientation of footing w.r.t axes [9]

The below equations give stiffness of soil when the footing is at surface level.

Table 1: Stiffness equations at surface given by Gazetas [9]

Degrees Of Freedom	Stiffness of foundation at Surface
Translational along x - axis	$K_x = \frac{GB}{2-\mu}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 1.2\right]$
Translational along y - axis	$K_y = \frac{GB}{2-\mu}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 0.4\frac{L}{B} + 0.8\right]$
Translational along z - axis	$K_z = \frac{GB}{1-\mu}\left[1.55\left(\frac{L}{B}\right)^{0.75} + 0.8\right]$
Rocking about x - axis	$K_{xx} = \frac{GB^3}{1-\mu}\left[0.4\left(\frac{L}{B}\right) + 0.1\right]$
Rocking about x - axis	$K_{yy} = \frac{GB^3}{1-\mu}\left[0.47\left(\frac{L}{B}\right)^{2.4} + 0.034\right]$
Rocking about x - axis	$K_{zz} = GB^3\left[0.53\left(\frac{L}{B}\right)^{2.45} + 0.51\right]$

3. PRESENT WORK

The model of building is G+6 storey RCC structure considered for the analysis. The building is symmetric in plan as shown in figure 5. The building has bay width of 5m in X and Y direction with 3m storey height. Slab is modelled as rigid diaphragm. Tuned mass damper is installed at top of building with 3% mass of structure. Non-linear time history analysis is carried out in ETABS2016 software using Imperial Valley, San Fernando, Northridge Earthquake records.

<u>Building Description and Material Properties:-</u>

Column = 300mm X 600mm
Beam = 300mm X 600mm
Slab thickness = 120mm

Live Load = 3 kN/m^2
Dead Load = 1.5 kN/m^2

Grade of Concrete/Steel = M20/Fe415
Imposed load on floor = 1.5 kN/m^2

Floor finish on all floor = 3 kN/m^2
Unit weight of RCC = 25KN/m3

<u>Seismic Properties (IS 1893:2002):-</u>

Seismic zone: V
Response reduction factor: 5

Importance factor: 1
Zone factor: 0.36

<u>Optimum Parameters of TMD:-</u>

Mass ratio: 3% of Structural weight

Sizes of TMD:-

Composite Column and Beam
Outer material = Fe250
Fill Material = M20 concrete

Size of Column = 130mmX130mm
Size of Beam = 130mmX130mm
Flange Thickness = 5mm (Fe250)

Slab Thickness = 123mm
Height of Weak storey at top = 5m

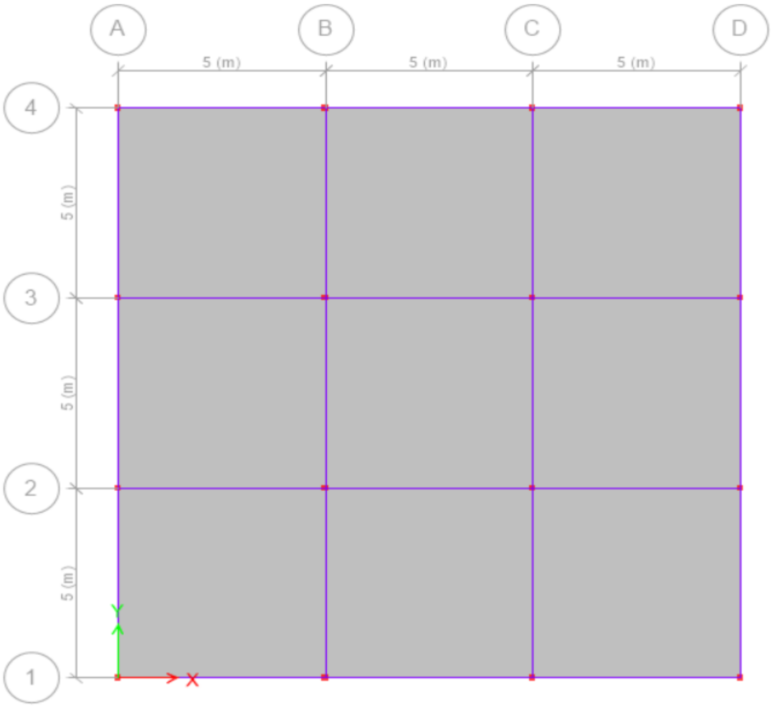
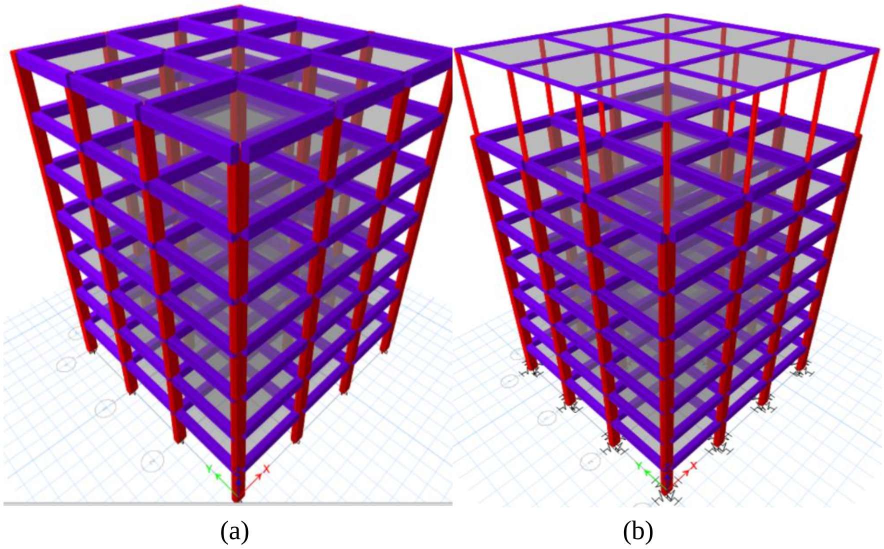


Figure 5: Plan view of Symmetrical Building



(a) (b)

Figure 6: (a) Building without TMD and SSI, (b) Building with TMD and SSI

Table 2: Detail of soil parameter considered

Soil Properties	Mass Density(KN/m3)	Shear Wave Velocity(m/sec)	Poisson's Ratio	Shear Modulus (kN/m2)
Hard	21	400	0.29	342507.65
7Medium	18	220	0.39	88807.34
Soft	17	170	0.40	500810.55

Table 3: Spring Constants for Different Soil Used in Foundation

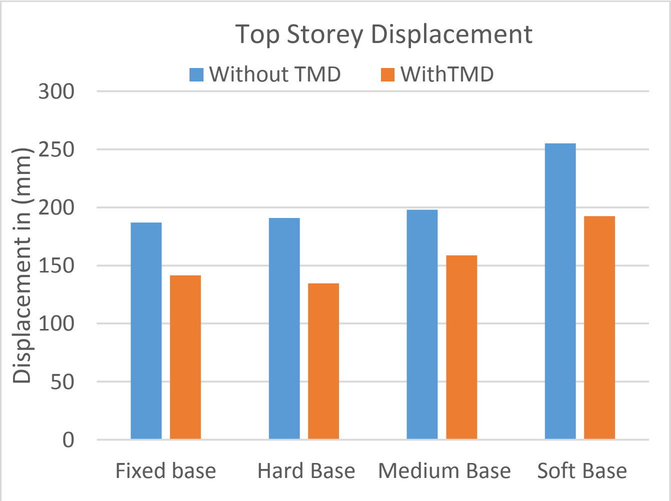
Soil Stiffness	Hard soil stiffness	Medium soil stiffness	Soft soil stiffness
K_x (kN/m)	1182000.243	328200.564	221200.321
K_y (kN/m)	1182000.432	228200.246	121200.689
K_z (kN/m)	942000.561	107200.512	37200.478
K_{xx} (kN-m/rad)	1321000.891	282100.623	222100.315
K_{yy} (kN-m/rad)	1540000.278	282400.891	124000.423
K_{zz} (kN-m/rad)	2354000.132	395400.756	225400.789

4. RESULT AND DISCUSSIONS

The response of symmetric building with tuned mass damper as soft storey by considering effect of soil structure interaction for El Centro ground motion is investigated in terms of displacement, storey drift and base shear.

A) Storey displacement

Figs. 7, 8, 9 shows the variation in the displacement of building without and with TMD by considering effect of SSI under three different earthquakes. From the analysis it can see that buildings having TMD which is 3%mass of building reduce the structural response significantly.



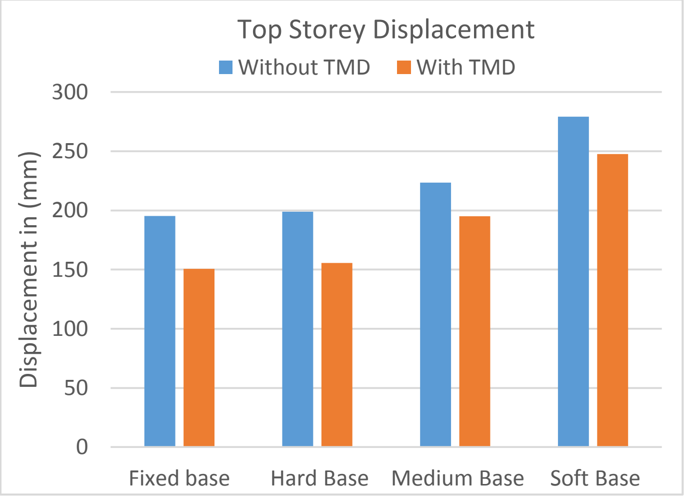


Figure 7: Storey Displacement Verses SSI for TH Imperial Valley   Figure 8: Storey Displacement Verses SSI for TH San Fer.

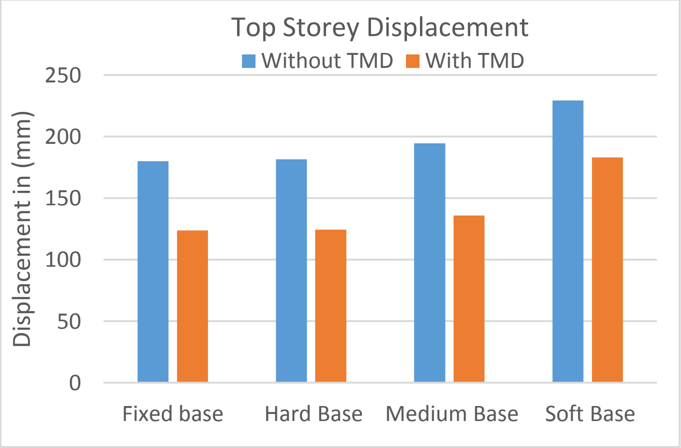


Figure 9: Storey Displacement Verses SSI for TH Northridge

B) Storey Drift

Figs. 10, 11, 12 shows the variation in the storey drift of building without and with TMD by considering effect of SSI under three different earthquakes. From the analysis it can see that buildings having TMD which is 3%mass of building reduce the structural response significantly.

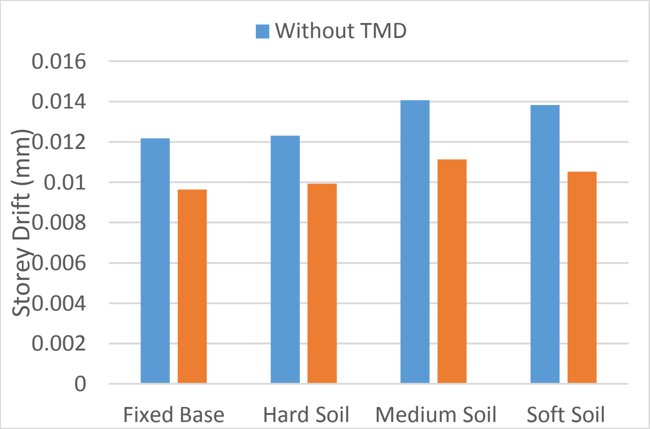


Figure10: Storey Drift Verses SSI for TH Imperial Valley

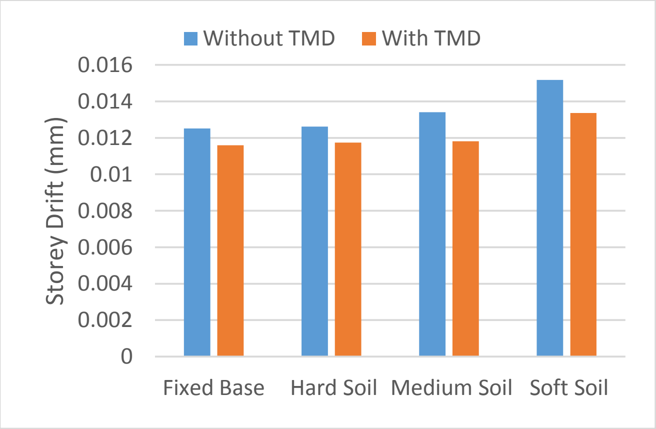


Figure 11: Storey Drift Verses SSI for TH San Fernando

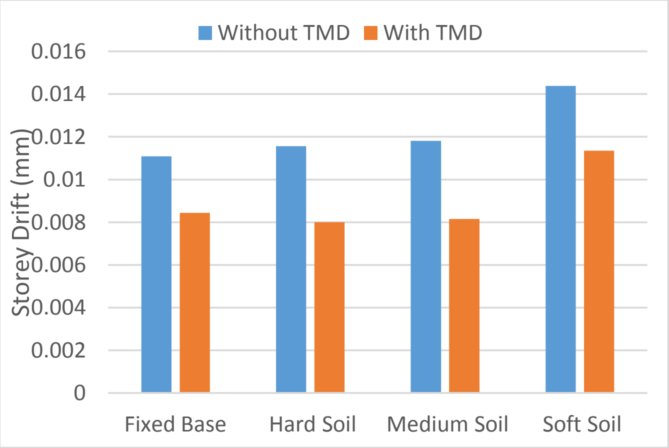


Figure 12: Storey Drift Verses SSI for TH Northridge

C) Storey Shear

Figs. 13, 14, 15 shows the variation in the storey shear of building without and with TMD by considering effect of SSI under three different earthquakes. From the analysis it can see that buildings having TMD which is 3%mass of building reduce the structural response significantly.

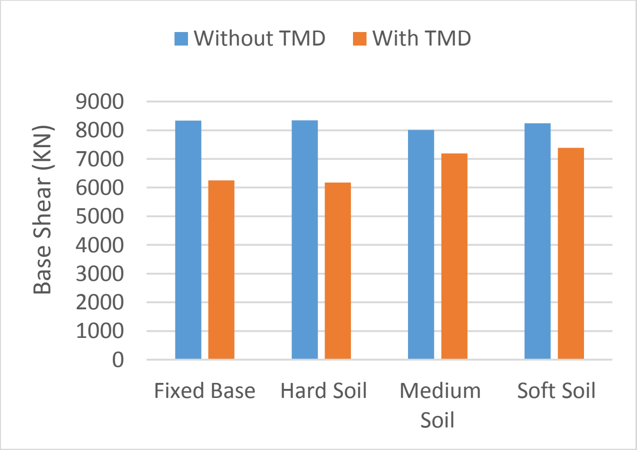


Figure 13: Storey Shear Verses SSI for TH Imperial

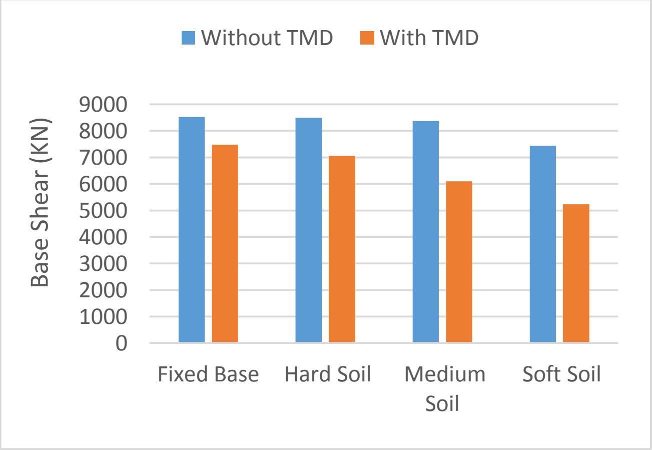


Figure 14: Storey Shear Verses SSI for TH San Fernando

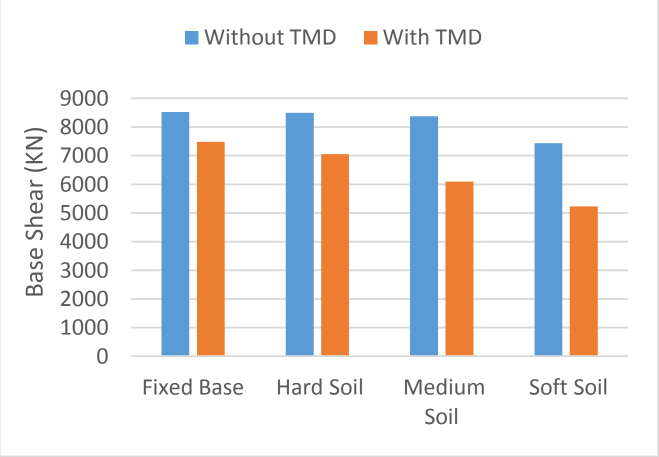


Figure 15: Strorey Shear Verses SSI for TH Northridge

From above results, the percentage reduction in top storey displacement, maximum storey drift, storey shear is found out for G+6 building with and without TMD resting on hard soil, medium soil, and soft soil for time history Imperial Valley, San Fernando, Northridge as shown in table below:

Table 4: Percentage reduction in displacement of G+6 building with TMD on different soil

% Reduction In Displacement				
Time History	Fixed Base	Hard Soil	Medium Soil	Soft Soil
Imperial Valley	28.61	29.51	19.88	17.88
San Fan	22.91	21.72	12.68	11.30
Northridge	31.28	31.51	29.94	20.19

Table 5: Percentage reduction in storey drift of G+6 building with TMD on different soil

% Reduction in Storey Drift				
Time history	Fixed Base	Hard Soil	Medium Soil	Soft Soil
Imperial Valley	20.82	19.28	20.86	23.91
San Fernando	7.35	6.99	11.89	12.02
Northridge	23.86	30.82843	30.98	21.03

Table 6: Percentage reduction in base shear of G+6 building with TMD on different soil

% Reduction in Base Shear				
Time History	Fixed Base	Hard Soil	Medium Soil	Soft Soil
Imperial Valley	24.96	25.97	10.21	10.36
San Fernando	12.29	17.02	27.20	29.65
Northridge	14.66	13.24	9.51	9.38

5. CONCLUSIONS

From the time history analysis on multistory building, it can be concluded that

A. The application of TMD in the form of soft storey at the top of high rise building is the simplest and feasible method for reducing structural response of the building.
B. By using 3% TMD, displacement of building can be reduce up to 32% for earthquake records of Imperial Valley, San Fernando and Northridge for fixed base laterally it decreased with soil condition.
C. Storey drift of the building with TMD as a soft storey can reduce up to 31% on hard soil, medium soil and soft soil.
D. Also found quite feasible for reducing the storey shear upto 26% for Imperial Valley and 15% for Northridge on fixed base and hard soil and then decreased on medium soil and soft soil and reduce upto 11%
E. Tuned mass damper in form of soft storey at top of the building is found to be effective reducing seismic response of a building on hard soil, medium soil and soft soil.

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